Defining Swallowing Function By Age Promises And Pitfalls Of Pigeonholing

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Abstract

Although it is well known now that age affects swallowing function, few data have been reported for larger bolus sizes, such as 20 mL or sequential cup swallows, and few have reported data on the "oldest old," or those older than 80 years. The purpose of this investigation was to provide data for future investigations on adults, ranging in age from 21 to older than 100 years, using thin liquid, puree, and solid boluses, ranging from 5 mL to 3 oz, and to add to the database regarding the effects of age, gender, bolus size, and bolus volume on swallowing function. Symptoms relating to swallowing dysfunction were also examined, including the presence of oropharyngeal residue and penetration-aspiration. Having incorporated data on larger swallows from older individuals than in the past and incorporating an 8-point penetration-aspiration scale, several findings emerged in this investigation that have not been clearly defined in prior research as being results of the aging process. Most prominently, it was observed that for older individuals laryngeal penetration is common, often with material remaining in the laryngeal vestibule after the swallow. Differences in oral transit duration and the duration of the onset of the pharyngeal swallow that may result from varying methodologies are also discussed. Implications are drawn for the appropriate evaluation and management of older adults with suspected dysphagia.

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Introduction

ALTHOUGH IT HAS BEEN observed that a hemispheric dominance exists for most individuals when swallowing,[1] the process involves the recruitment of a fairly widespread neural network.[2] Periventricular white matter changes have been reported with increasing age,[3] and numerous changes in swallowing function have been reported, including changes in oral[4] and pharyngeal sensation,[5] lingual pressure generation,[6] pharyngeal pressure generation,[7,8] and an array of swallowing duration measures.[9-11] While some have observed these changes to have minimal effect on swallowing safety for older adults,[6] others have stated that "dysphagia" is relatively common in older individuals, occurring in the oral stage in 63% of older adults, the pharyngeal stage in 25%, and the esophageal stage in 36%.[12] With larger boluses and sequential drinking, penetration reportedly remains uncommon in normal individuals, though more prevalent in the elderly, with a wide array of swallowing patterns that may be inherent to the individual.[13]

With changes apparent in the neurologic network and at least some aspects of swallow physiology, it becomes imperative to consider aging when evaluating patients for oropharyngeal dysphagia. Overmanaging elderly (ie, restricting diet or implementing compensatory strategies that may not be needed) on the basis of false assumptions could lead to unnecessary restrictions on nutritional intake and quality of life. Likewise, undermanagement could lead to negative consequences,

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such as dehydration, malnutrition, pneumonia, and death.[14] If the effects of age on the biomechanics of swallowing function can be defined regarding swallowing durations, penetration-aspiration, and residue, then clinicians would have a better chance of appropriately managing the resulting symptoms of disease.

The primary purpose of this investigation was to collect normative data on an array of swallowing duration measures, residue, number of swallows, and penetration-aspiration for use with future and concurrent investigations. Prior studies have provided valuable data and insight into the changes in swallow physiology across the lifespan, but have either examined a limited range of consistencies or have employed only 1 or 2 small bolus sizes. Normal individuals in this investigation were divided into 4 age groups (21–39, 40–59, 60–79, and $\geq$80) and provided with thin liquid, puree, and solid consistencies in volumes for thin liquid ranging from 5 mL to 3 oz and including 10- and 20-mL boluses. This provides a wider range of measures across a wider range of ages than previously reported. The effects of gender, bolus size, and bolus volume were also investigated.

METHODS

Participants

Eighty normal male and female volunteers, ranging in age from 21 to 103 years, were recruited to participate at 1 of 2 sites: the Department of Veterans Affairs Medical Center (VA Medical Center), Nashville, Tenn; and the former research laboratory of the principal investigator at The University of Tennessee, Knoxville. All procedures were approved by the Committee for the Protection of Human Subjects at Vanderbilt University/VA Medical Center, Nashville, and The University of Tennessee. Informed consent was obtained from all participants prior to the initiation of the examination procedures. In all, 81 normal, healthy participants with no history of swallowing problems were evaluated. One participant was disqualified because of multiple events of aspiration, leading the investigators to believe that an underlying pathology causing dysphagia had not been identified in the individual. One participant's study was impossible to review because of poor positioning at the time of the study. Thus, 79 participants were entered into the final evaluation in 1 of the following 4 age groups: 21–39 years, 40–59 years, 60–79 years, 80 years and older. Ten men and 10 women comprised all but one group, from which the unreadable study was removed.

Screening

Each participant, prior to examination of swallowing with videofluoroscopic swallow study (VFSS), was screened for history of neurological involvement or structural abnormalities that would interfere with swallowing. Each participant also passed the Modified Mini-Mental State Examination (3MSE),[15] administered by the study clinician. The original test, Mini-Mental State Examination, has been widely used for dementia. The 3MSE incorporates 4 additional test items to sample a wider array of cognitive responses and enhance reliability and validity. Rather than 0–30, scores range from 0 to 100. No participant was entered into the study with a score of less than 70. Each participant also passed a cranial nerve, oral motor, and structural examination. Women between the ages of 20 and 50 completed a home pregnancy test.

Swallowing assessment

Following the 3MSE and oral motor examinations, the VFSS was conducted. Participants were seated upright in a chair for the duration of the study. The VFSS examinations were conducted with mobile C-arm x-ray units (model 7600 in Knoxville and model 9600 in Nashville) (OEC Diasonics, Inc., Salt Lake City, Utah). The units were run either by a radiology technologist (Nashville) or by a radiologist (Knoxville). Studies were recorded on to Panasonic Super VHS Pro Line Multiplex

Table 1. Duration measures for oropharyngeal swallowing function

Measure	Description of measure
Oral transit duration	Beginning of posterior movement of the bolus to the bolus head at ramus of mandible
Stage transition duration	Arrival of first material at ramus of mandible to initiation of maximal hyoid excursion
Stage transition duration 2	From bolus head at ramus of mandible to initiation of maximal hyoid excursion
Pharyngeal transit duration	From bolus head at ramus of mandible to bolus tail entering cricopharyngeus
Pharyngeal response duration	From initiation of maximum hyoid excursion to hyoid return to rest
Duration of hyoid maximum elevation	From hyoid first maximum elevation to hyoid last maximum elevation
Duration of hyoid maximum anterior excursion	From first frame showing maximum anterior hyoid movement to last frame showing maximum anterior hyoid movement
Duration of opening of upper esophageal sphincter	From upper esophageal sphincter opening to its closing
Total swallow duration	From beginning posterior bolus movement to hyoid return to rest

videocassette recorders, and a 100-ms time clock was superimposed on to the study via an attached digital videotimer (FOR-A, Inc, Tokyo, Japan). Studies were then stored on 1/2 in. 3M T60 Broadcast S-VHS videocassette tapes.

The fluoroscopic camera was focused on the lips anteriorly, the pharyngeal wall posteriorly, the hard palate superiorly, and just below the upper esophageal segment inferiorly. Four bolus consistencies were provided to each participant during the VFSS in the following order: 3 swallows of 5-mL thin liquid bolus, 3 swallows of 10-mL thin liquid bolus, and 2 swallows of 20-mL thin liquid bolus—each a 50:50 mixture of water and E-Z-HD Barium Sulfate Powder for Suspension (E-Z EM, Inc., Westbury, NY). These swallows were followed by two, 5-mL swallows of puree (3 parts applesauce to 1 part barium powder) and 2 solids (1/4 Lorna Doone shortbread cookie coated with E-Z Paste Barium Sulfate Esophageal Cream; E-Z EM, Inc.). The final swallow was a 3-oz swallow with thin liquid. Patients were instructed to drink the 3-oz thin liquid with consecutive swallows. All swallows were viewed laterally.

Duration measures

The principal investigator trained to criteria on all duration measures at the VA Medical Center GRECC in Madison, Wis, and was the primary reviewer and rater for all studies. The following duration measures were analyzed (Table 1): oral transit duration (OTD), stage transition duration (STD), stage transition duration 2 (STD2), pharyngeal transit duration (PTD), pharyngeal response duration (PRD), duration of hyoid maximum elevation (DOHME), duration of hyoid maximum anterior excursion (DOHMAE), duration of opening of the upper esophageal sphincter (DOOUES), and total swallow duration (TSD). Measures were calculated mathematically from times that are recorded for specific physiologic markers. These markers have been provided in Table 1. Frame-by-frame analysis was employed to determine the time (in milliseconds) of the beginning and end points of each measure according to the

Table 2. Eight-point penetration-aspiration scale

Score	Description
1	Material does not enter the airway
2	Material enters the airway, remains above the vocal folds, and is ejected from the airway
3	Material enters the airway, remains above the vocal folds, and is not ejected from the airway
4	Material enters the airway, contacts the vocal folds, and is ejected from the airway
5	Material enters the airway, contacts the vocal folds, and is not ejected from the airway
6	Material enters the airway, passes below the vocal folds, and is ejected either from the trachea into the larynx or completely out of the airway
7	Material enters the airway, passes below the vocal folds, and is not ejected from the trachea despite effort
8	Material enters the airway and passes below the vocal folds, and no spontaneous effort is made to eject it

operational definitions. In addition to duration measures listed above, each swallow was rated on an 8-point penetration-aspiration scale.[16] This scale has been provided in Table 2. Residue was rated in the oral cavity, the valleculae, the pyriform sinuses, and the upper esophageal sphincter using a 3-point scale, where 0 = no residue, 1 = trace coating, and 2 = pooling. The number of swallows per bolus was also recorded.

Reliability

Interjudge reliability was determined by having a trained graduate student in speech-language pathology analyze 20% of all VFSS examinations. Intrajudge reliability was determined by having the principal investigator view and rate each measure on 20% of the VFSS examinations. Interjudge and intrajudge reliability were calculated using intraclass correlation coefficients. All duration measures, penetration-aspiration scores, and residue scores were rated with good interjudge and intrajudge reliability ($P \leq .01$).

Statistical analyses

Means, ranges, and standard deviations were calculated for each age and gender group, as well as for each bolus size and consistency, on SPSS 14 software (SPSS, Inc.). The data were then submitted to a 4-way factorial analysis of variance with 4 between subject factors (age, gender, bolus size, and bolus consistency). The significance level was set a priori at $P \leq .05$.

RESULTS

Age

Mean values for each swallowing duration measure according to age have been provided in Table 3. Duration measures that were significantly ($P \leq .05$) affected by age are indicated with an asterisk and include OTD, PTD, TSD, PRD, STD2, DOHMAE, and DOOUES. For measures that are not, overall, significantly affected by age, substantive differences may still exist between two age groups; but, statistically, the overall progression of age did not have a significant impact on the mean duration for that measure. OTD decreased with age. All other measures, even those that were not significantly affected by age, STD, and DOHME, increased overall with increasing age. STD was longer in the youngest age group in this investigation than for all 3 other groups. That group withstanding, STD did increase between the second and fourth age groups. These trends are shown in Figures 1a–c.

In prior research regarding STD (Kim et al, unpublished data, 2007),[17] data were analyzed only for 5- and 10-mL thin liquid boluses, and STD was observed to increase significantly with age. A "delayed swallow," the

Table 3. Effects of age on measures of oropharyngeal swallowing duration*

Age	OTD†	PTD†	TSD†	PRD†	STD	STD2†	DOHME	DOHMAE†	DOOUES†
21–39	0.51	0.18	1.22	0.68	0.42	0.01	0.13	0.16	0.61
40–59	0.53	0.40	1.38	0.77	0.30	0.10	0.16	0.14	0.59
60–79	0.41	0.64	1.36	0.86	0.30	0.11	0.16	0.13	0.56
≥80	0.41	0.39	1.40	0.80	0.43	0.11	0.19	0.19	0.64

*All measures reported as mean durations (seconds) across all bolus sizes and consistencies. OTD indicates oral transit duration; PTD, pharyngeal transit duration; TSD, total swallow duration; PRD, pharyngeal response duration; STD, stage transition duration; DOHME, duration of hyoid maximum elevation; DOHMAE, duration of hyoid maximum anterior excursion; and DOOUES, duration of open upper esophageal sphincter.

†Significant at $P \leq .05$.

target measurement of STD, is predominantly a risk for thin liquid aspiration. Therefore, for the purposes of comparison, STD and STD2 were also analyzed independently for 5- and 10-mL thin liquid boluses. For these thin liquid consistencies, STD and STD2 increased with age, and age had a significant effect on both measures (Fig 2).

Gender

Mean values for each swallowing duration measure according to gender have been provided in Table 4. Measures that were significantly ($P \leq .05$) affected by gender are indicated by an asterisk and include PTD, PRD, STD2, and DOOUES. Both OTD and TSD approached significance. PTD, PRD, and

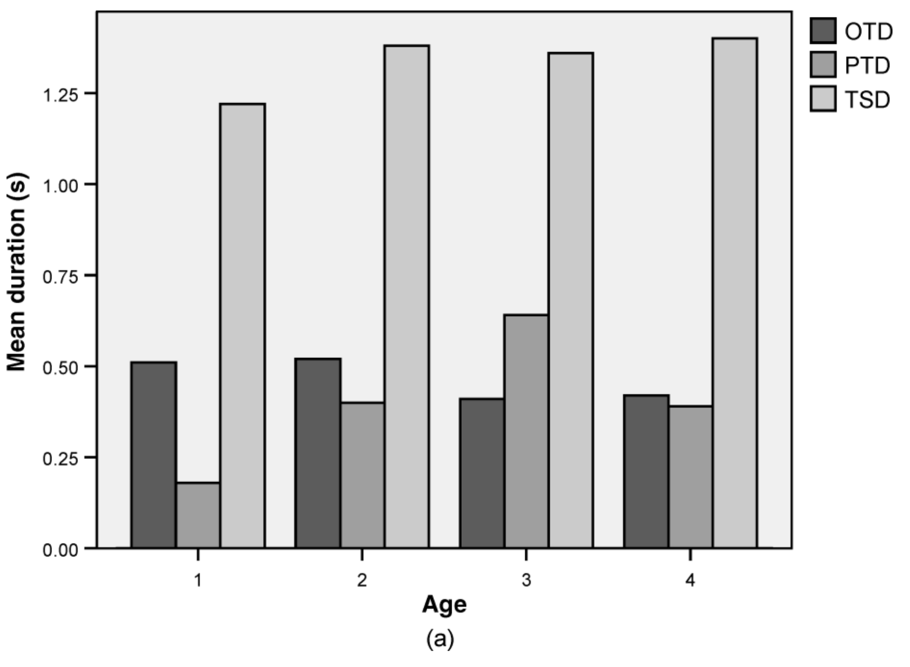

Figure 1. Effects of age on (a) mean oral transit duration (OTD), pharyngeal transit duration (PTD), and total swallow duration (TSD); (b) mean pharyngeal response duration (PRD), stage transition duration (STD), and stage transition duration 2 (STD2); and (c) mean duration of hyoid maximum elevation (DOHME), duration of hyoid maximum anterior excursion (DOHMAE), and duration of opening of the upper esophageal sphincter (DOOUES). Ages: 1 = 21–39; 2 = 40–59; 3 = 60–79; and 4 = 80 and older. (*Continues*)

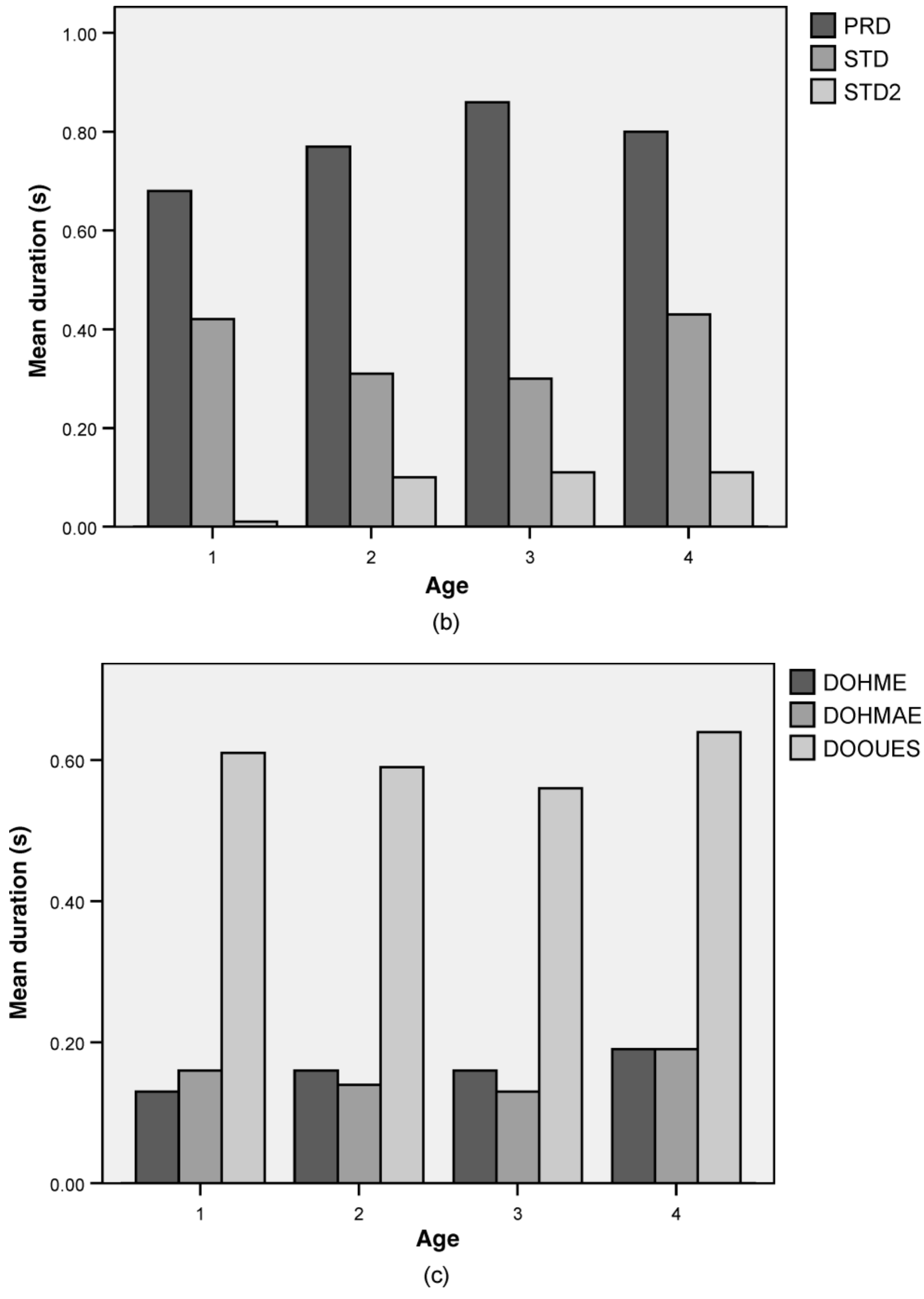

Figure 1. (*Continued*) Effects of age on (a) mean oral transit duration (OTD), pharyngeal transit duration (PTD), and total swallow duration (TSD); (b) mean pharyngeal response duration (PRD), stage transition duration (STD), and stage transition duration 2 (STD2); and (c) mean duration of hyoid maximum elevation (DOHME), duration of hyoid maximum anterior excursion (DOHMAE), and duration of opening of the upper esophageal sphincter (DOOUES). Ages: 1 = 21–39; 2 = 40–59; 3 = 60–79; and 4 = 80 and older.

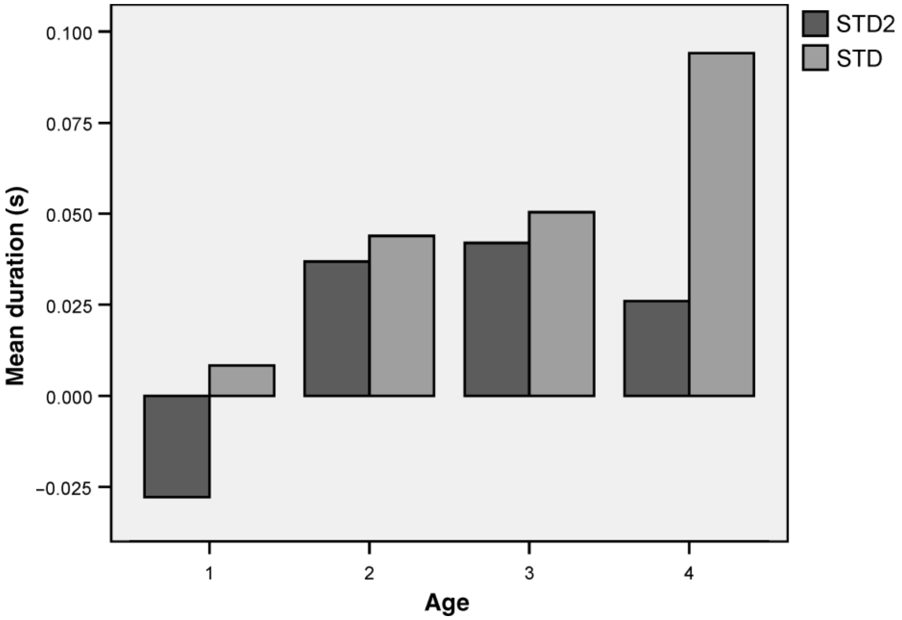

Figure 2. Effects of age on stage transition (STD) and stage transition 2 (STD2) for 5- and 10-mL thin liquid boluses. Ages: 1 = 21–39; 2 = 40–59; 3 = 60–79; and 4 = 80 and older.

STD2 were significantly longer in men than in women, as were the less significant variables OTD and TSD. DOOUES was longer in women than in men. The significant effects of gender on swallowing duration measures are shown in Figure 3.

Bolus consistency

Mean values for each swallowing duration measure according to bolus consistency (thin liquid, puree, solid) have been provided in Table 5. Measures that were significantly ($P \leq .05$) affected by consistency are indicated by an asterisk and include OTD, PTD, TSD, STD, STD2, and DOHME. Each of these duration measures tended to increase with increasing bolus consistency. OTD was longer for puree than solid. This is likely due to a more anterior onset for bolus propulsion with puree than solid. Solid material, once masticated, tended to rest further back on the tongue before the swallow was initiated. PRD, DOHMAE, and DOOUES were not substantively different

Table 4. Effects of gender on measures of oropharyngeal swallowing duration*

Gender	OTD†	PTD‡	TSD§	PRD‡	STD	STD2‡	DOHME	DOHMAE	DOOUES‡
Male	0.50	0.44	1.39	0.80	0.32	0.11	0.17	0.15	0.58
Female	0.44	0.37	1.30	0.77	0.38	0.06	0.15	0.16	0.61

*All measures reported as mean durations (seconds) across all bolus sizes and consistencies. OTD indicates oral transit duration; PTD, pharyngeal transit duration; TSD, total swallow duration; PRD, pharyngeal response duration; STD, stage transition duration; DOHME, duration of hyoid maximum elevation; DOHMAE, duration of hyoid maximum anterior excursion; and DOOUES, duration of open upper esophageal sphincter.

†$P = .06$.

‡Significant at $P \leq .05$.

§$P = .07$.

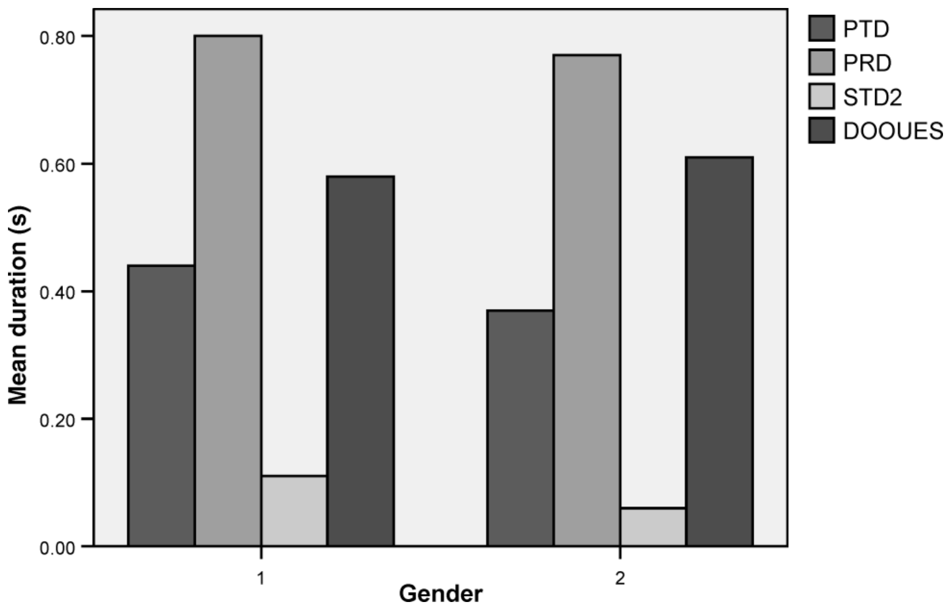

Figure 3. Significant effects of gender on pharyngeal transit duration (PTD), pharyngeal response duration (PRD), stage transition duration 2 (STD2), and duration of opening of the upper esophageal sphincter (DOOUES). Gender: 1 = male; 2 = female.

across consistency but tended to decrease in duration as consistency increased. The significant effects of bolus consistency on swallowing duration measures are shown in Figures 4a and b.

Bolus volume

Mean values for each swallowing duration measure according to bolus volume (5, 10, and 20 mL) have been provided in Table 6. Measures that were significantly ($P \leq .05$) affected by bolus volume are indicated by an asterisk and include TSD, STD, STD2, and DOOUES. Each measure tended to increase in duration with increasing bolus volume. Other measures showed great variability across consistency with no clear trends. The significant effects of bolus volume on measures of swallowing duration are shown in Figure 5.

Residue, number of swallows, and penetration-aspiration

Scores on the 8-point penetration-aspiration scale were significantly associated

Table 5. Effects of bolus consistency on measures of oropharyngeal swallowing duration*

Consistency	OTD†	PTD†	TSD†	PRD	STD†	STD2†	DOHME†	DOHMAE	DOOUES
Thin liquid	0.38	0.35	1.23	0.79	0.07	0.05	0.15	0.16	0.61
Puree	0.74	0.46	1.59	0.75	0.37	0.12	0.21	0.15	0.58
Solid	0.57	0.57	1.54	0.77	1.40	0.20	0.15	0.15	0.58

*All measures reported as mean durations (seconds) across ages and gender. OTD indicates oral transit duration; PTD, pharyngeal transit duration; TSD, total swallow duration; PRD, pharyngeal response duration; STD, stage transition duration; DOHME, duration of hyoid maximum elevation; DOHMAE, duration of hyoid maximum anterior excursion; and DOOUES, duration of open upper esophageal sphincter.

†Significant at $P \leq .05$.

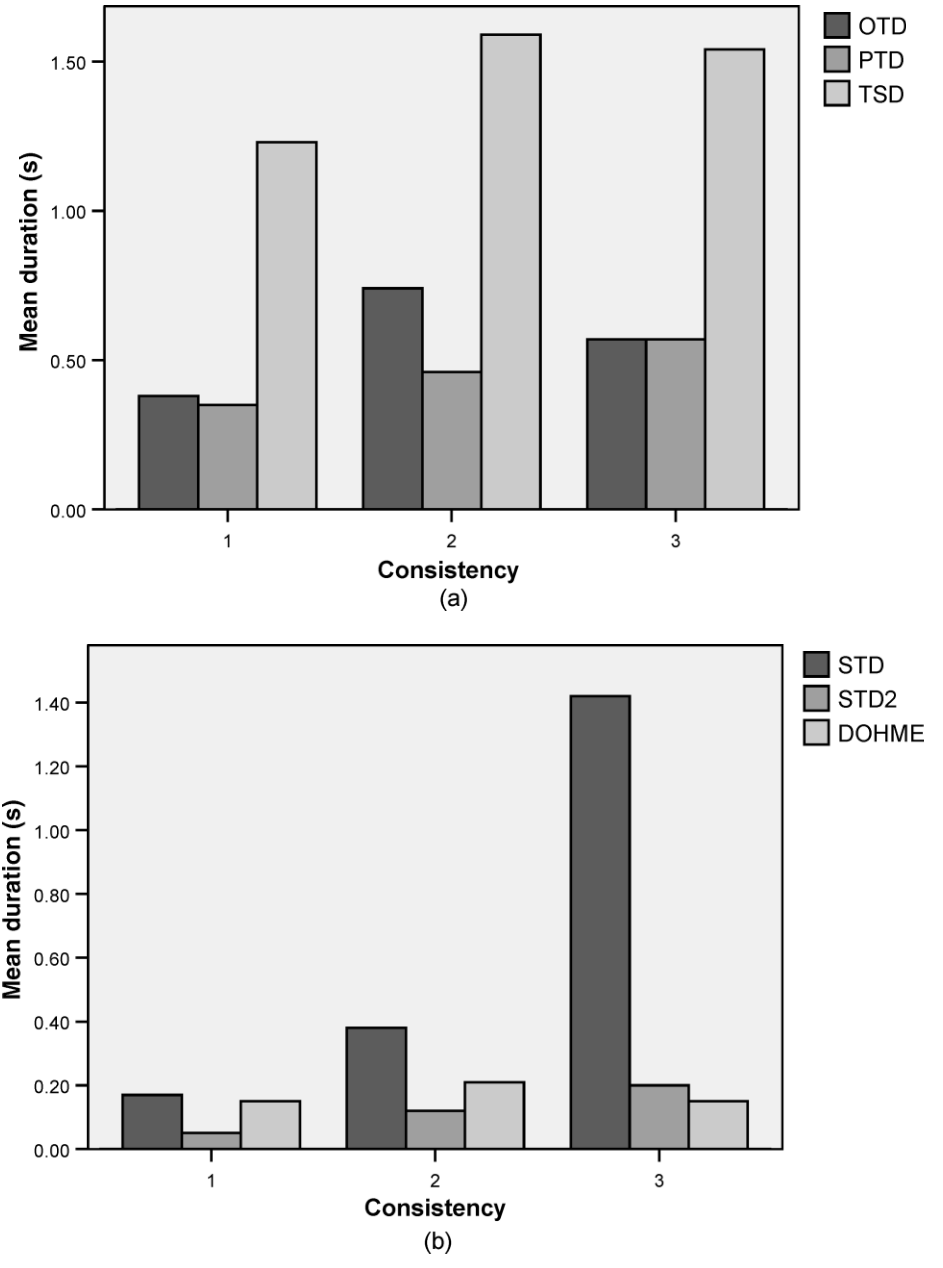

Figure 4. Significant effects of bolus consistency on (a) oral transit duration (OTD), pharyngeal transit duration (PTD), and total swallow duration (TSD); (b) stage transition duration (STD), stage transition duration 2 (STD2), and duration of hyoid maximum elevation (DOHME). Consistencies: 1 = thin liquid; 2 = puree; and 3 = solid.

with age (P = .018), as were the scores on the 8-point scale for the 3-oz swallow rated independently (P = .000) (Fig 6). No one in the youngest age group (21–39 years) received a score of more than 3 on regular bolus swallows (5, 10, and 20 mL) and only 1 swallow for 1 individual was given a score of "3." There were 5 individuals who

Table 6. Effects of bolus size on measures of oropharyngeal swallowing duration*

Size	OTD	PTD	TSD†	PRD	STD†	STD2†	DOHME	DOHMAE	DOOUES†
5 mL	0.41	0.35	1.21	0.79	0.06	0.01	0.15	0.15	0.58
10 mL	0.38	0.34	1.21	0.80	0.05	0.04	0.16	0.16	0.61
20 mL	0.35	0.36	1.33	0.79	0.12	0.14	0.14	0.15	0.65

*All measures reported as mean durations (seconds) across age, gender, and consistency. OTD indicates oral transit duration; PTD, pharyngeal transit duration; TSD, total swallow duration; PRD, pharyngeal response duration; STD, stage transition duration; DOHME, duration of hyoid maximum elevation; DOHMAE, duration of hyoid maximum anterior excursion; and DOOUES, duration of open upper esophageal sphincter.

†Significant at $P \leq .05$.

were rated as having at least one "2" on the penetration-aspiration scale in the youngest age group. A score of "2" means that barium entered the laryngeal vestibule but whatever material entered was forced back into the pharynx by the normal swallowing pressures. This can be as little as a trace amount coating the underside of the epiglottis as it inverts. In the oldest age group (≥80 years), 12 individuals scored at least one "2" on regular bolus swallows and 7 of those 12 scored 3 or higher—up to a score of 7 for 1 participant. Penetration-aspiration scores were significantly affected by bolus size and consistency, meaning that most of the higher penetration-aspiration scores (deeper penetration of the larynx) occurred on larger volumes (10 or 20 mL) of thinner consistency (thin liquid). At the highest amount provided, the 3-oz swallow, 9 participants in the youngest age group had at least some laryngeal penetration (≥2). Fifteen participants in the 40–59 years age group scored at least a 2 on the penetration-aspiration scale, and, of those, 6 were rated a 3 or higher when swallowing 3 oz consecutively. Moreover,

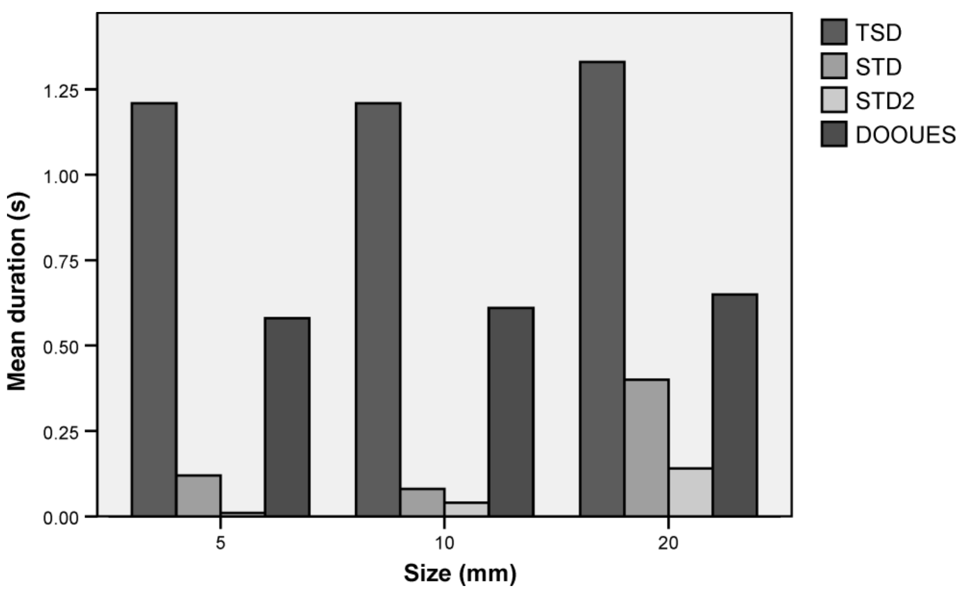

Figure 5. Significant effects of bolus size on total swallow duration (TSD), stage transition duration (STD), stage transition duration 2 (STD2), and duration of opening of the upper esophageal sphincter (DOOUES).

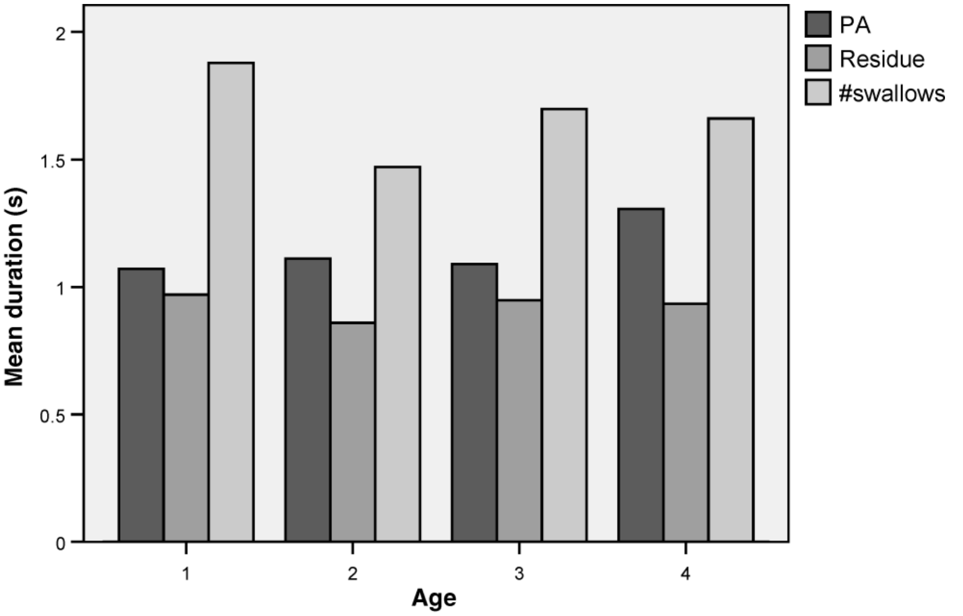

Figure 6. Mean penetration-aspiration (PA) score, oropharyngeal residue rating (residue), and number of swallows (#swallows) per bolus by age. Ages: 1 = 21–39; 2 = 40–59; 3 = 60–79; and 4 = 80 and older.

23 individuals in the upper 2 age groups, encompassing those 60 years and older, experienced some laryngeal penetration on the 3-oz swallow.

Residue, rated as none (0), trace coating (1), or pooling (2), provided little variation on a swallow-to-swallow basis. No scores of 2 were observed in this investigation for any age group, and less than 10% of all swallows were scored 0, meaning that almost everyone experienced trace coating (1). Nonetheless, residue was significantly affected by age; twice as many younger adults received 0 residue ratings as older adults. Residue ratings of 1 were more likely than residue ratings of 0 to elicit multiple swallows. More than 90% of all boluses across age groups were ingested in 1 or 2 swallows, but the number of swallows did increase in the oldest 2 age groups at a significant rate (up to 4 per bolus) (see Fig 6).

Gender effects were observed for the presence of residue ($P = .007$) as well as for the number of swallows ($P = .001$). Residue was present to a greater extent (higher ratings) in men than in women, yet women tended to swallow more times per bolus.

Penetration-aspiration scores decreased with bolus consistency ($P = .000$) and increased with bolus size ($P = .001$). Residue and the number of swallows per bolus were significantly affected by bolus consistency and size as well. Residue and number of swallows per bolus increased with increasing bolus size but decreased with increasing viscosity.

DISCUSSION

Age

The primary purpose of this investigation was to collect measures of oropharyngeal swallowing duration and penetration-aspiration across the adult age span and across a wider range of bolus sizes and consistencies than in previous reports. These data could be employed for comparison with adults with neurological impairment in subsequent investigations and add to the developing literature on the effects of age, gender, bolus size, and bolus volume on swallowing function. Most studies have examined 1 or 2 age groups, and few have incorporated the "oldest old," or those older than 80 years. Moreover, studies have typically focused on one aspect of the effects of age, examining patients across either bolus size or bolus consistency, and only a few investigations have examined normal participants with larger volumes of liquid, such as 20 mL (reference 18) or sequential swallows (reference 13). Finally, few reports exist regarding the effects of aging on other symptoms of swallowing, such as oropharyngeal residue and penetration-aspiration. Much of the data collected on normal individuals was collected prior to the development of an 8-point penetration-aspiration scale.[16] It was anticipated that this scale could be beneficial for examining changes with age in a way that prior analyses were not sensitive enough to detect. This is the largest data set to our knowledge that incorporates normal individuals, ranging in age from 21 to older than 100 years, and incorporates thin liquid, puree, and solid and bolus sizes, ranging from 5 mL to 3 oz.

It has been proposed that swallowing changes with age. Oral sensation and pharyngeal sensation have been shown to decrease with age,[4,5] as have oropharyngeal pressures with swallowing[7,8] and oral isometric strength tasks.[6] More recently, patterns of breathing and swallowing have also been observed to change with age.[19,20] In general, the time required by a bolus to pass through the oropharynx and into the upper esophagus has been shown to increase with age.* However, not all swallowing duration measures have been observed to change substantively with age.[11,21]

Increased time to swallow has the potential to create a number of problems. Primarily, slower swallowing means slower bolus passage through the oropharynx and extended time periods for laryngeal exposure to potential aspiration. Aspiration is one of the primary concerns when evaluating patients for dysphagia and when making dietary and treatment recommendations. According to these results, scores on an 8-point penetration-aspiration scale do worsen with age, especially for larger volumes of liquid boluses. This is, perhaps, the most important finding in this analysis of normative data: normal people experience laryngeal penetration. Previous data on normal aging and swallowing rarely mention the occurrence of penetration-aspiration. As stated previously, this may be, in part, due to the lack of a valid scale for reporting penetration. The 8-point scale is a reliable scale that meets the statistical assumptions necessary for ordinality and intervality.[24] One recent investigation noted an infrequent occurrence of penetration-aspiration on sequential swallows.[13] The study did utilize the 8-point scale, and though occurrences of penetration-aspiration were reportedly infrequent, they were more common with older participants than with younger ones. These current data were derived from patients as old as 103 years of age and incorporate bolus sizes from 5 mL to 3 oz. While Daniels et al[13] examined sequential swallows with a straw, participants in this investigation drank from a cup. One could argue that use of a straw creates a natural chin tuck position, which may curb the potential for penetration-aspiration, whereas continuous drinking from a cup might actually make the occurrence of penetration-aspiration more likely due to the angle of the head/neck.

Twenty-one people, 6 in the second age group and 5 in each of the others, experienced at least 1 episode of laryngeal penetration on either 5-, 10-, or 20-mL thin liquid bolus. It is, thus, not *un*common to observe trace penetration in younger adults. More than half of patients in the upper 2 age brackets were observed to have laryngeal penetration with liquid boluses, 25% of whom scored 3 or higher on the penetration-aspiration scale, meaning that material either remained just inside the laryngeal vestibule or traveled deeper into the airway. Forty percent of all participants in the oldest age group (≥80 years), scored a 3 or higher on some bolus(es). Thus, it was actually common for

*References 3, 9, 10, 11, 17, 21–23.

thin liquid to penetrate the larynx and even to have some material remain in the upper part of the laryngeal vestibule. For larger boluses, such as 20 mL, such penetration was more common than for smaller boluses (5 and 10 mL). When drinking 3 oz consecutively,[25] penetration of the larynx by the bolus was far more common than not. This is supported by research indicating a larger threshold for activating the glottal closure reflex in healthy, older individuals,[5] and calls into question the use of a 3-oz swallow as a screening mechanism for dysphagia. Despite its overall sensitivity for detecting aspiration, high numbers of false positives have been reported with this measure.[26]

Although research has clearly demonstrated that there is more to aspiration pneumonia than aspiration,[27] many clinicians, and, moreover, radiologists, remain timid about laryngeal penetration and are all too ready to terminate a study or thicken liquid at the first sign of barium in the airway. Based on these data, the occurrence of some type of laryngeal penetration is more likely than not in older adults. Although quantification of penetration-aspiration on VFSS is very difficult, it appeared that amounts in this study could be described as trace, and clinicians should be careful not to interpret all episodes of laryngeal penetration as abnormal or in need of management. It is likely that barium residing in the larynx eventually passes below the vocal folds, but in small amounts it is unlikely that a substantive amount would ever reach the lungs. Although it is possible that some of these participants could have complications result at some point in time from laryngeal penetration, they were considered "normal" on the basis of their overall profile of health status and swallowing function. In other words, we do not know for certain that these small amounts of penetration observed are not or will not be problematic for some of the participants. Regardless, overtreating and overcompensating is a possible risk, and these data provide some evidence that penetration of thin liquid, and possibly even aspiration, in small quantities, is normal for older adults.

Despite the frequent occurrence of penetration of liquid boluses, pooling of bolus residue (2 on the scale employed in this investigation) was uncommon. It has been reported[8] that hypopharyngeal negative pressure and upper esophageal sphincter relaxation decrease with age, which would, logically, increase pharyngeal residue—at least in the pyriform sinuses. Nonetheless, that investigation also suggested, as does this one, that normal bolus flow appears to be able to continue in most elderly despite these changes. Prior research has concluded that propulsive activity begins earlier and persists longer in the elderly, perhaps as a means of compensation that ensures transfer of the bolus to the esophagus[27] in the face of declining speed of bolus propulsion. Perlman and colleagues[7] reported similar increases in duration of pressure several years prior to that investigation. The fact that swallowing duration measures and bolus movement slow down with age without apparent increase in bolus residue may provide symptomatic support for increased pharyngeal pressures acting in a compensatory fashion. In other words, duration increases to compensate for diminished strength. We find additional support for this concept when considering reports that the extent of anterior-posterior upper esophageal sphincter opening diminishes with age,[28,29] whereas its durations increase or remain stable, and, again, residue only modestly increases.

Despite the lack of residue pooling, trace coating, in the current investigation, was almost standard. On the basis of these results, it can almost be said that if one does not exhibit some type of coating of the tongue or pharynx that one is swallowing something other than barium. Thus, the scale of no residue, coating, or pooling, albeit easy for reliability purposes, may not be sensitive enough to define such an occurrence in normal populations. Regardless, enough individuals in the older age groups exhibited oropharyngeal coating of barium to make the rating significant for an age effect than did the younger age groups.

While this study concurs with previous findings in that swallowing duration measures are generally slower with increasing age, a few unexpected duration measures are reported here as well. For example, in some previous research,[30,31] OTD, referred to as "oral transit time," was reported to increase with age. While other investigations have reported no significant changes in OTD,[11,21] in this investigation a significant change was found, only in the opposite direction we expected. OTD decreased with age rather than increasing. Two observations in this study may account for this finding. First, OTD was timed from the initiation of posterior bolus movement to the point where the head of the bolus passed the ramus of the mandible. It has been reported that in this world in which we live, there are tippers and there are dippers.[32] Tippers keep the oral bolus up on the tongue prior to initiating posterior movement. Dippers hold the bolus below the tongue in the anterior sulcus of the mouth. Thus, OTD can vary widely depending on how it is measured and how many tippers versus dippers are recruited. In an effort to account for this phenomenon across participants, we measured dippers from the point at which the bolus was level with the tongue and moving posteriorly. This is not always easy to discern and is complicated further by radiologists who are hesitant to turn the videofluoroscopy unit on quickly and keep the field wide open on videofluoroscopy, which is the second observation that could have affected these results. The concern for overexposure is understandable. Nonetheless, many times the initiation of oral transit is obliterated or already begun before it can be viewed; this could contribute to variance not only within this study but also across different studies. To expand upon the tipper/dipper phenomenon, some individuals hold the bolus not only up on the tongue but also in the back of the mouth, so that all that is required for oral transit is to release the soft palate's grip on the back of the tongue and let the bolus fall. In reexamining a selection of VFSSs, a number of the oldest patients in this investigation held the bolus in the back of the mouth. This could be a compensatory technique for overcoming difficulty with oral bolus transit, or it could be a natural way for many people to hold the bolus. Regardless, OTD varied with the positioning of the bolus prior to posterior movement, and it tended to be more posterior with older adults. For these reasons, measuring the duration of oral bolus transit can vary widely. This finding should be considered when attempting to utilize "normal" swallowing durations to define what is "abnormal."

Likewise, our main results for STD, or the timing of the onset of the pharyngeal swallow in relation to the end of the oral stage, were also surprising. In prior research utilizing STD,[11,17] the effects of age on the onset of the pharyngeal swallow were significant. Another measure, pharyngeal delay time (PDT), was also observed to prolong with age, though not significantly.[21] While Robbins et al[11] employed 2-mL boluses, Logemann et al[21] employed 1- and 10-mL boluses and Kim et al[17] employed 5- and 10-mL boluses. Bolus volume has been reported to affect the onset of the pharyngeal swallow as well,[9,10] typically decreasing the time to onset as the bolus volume increases. Regardless, it appears important to consider volume size, as well as consistency, when comparing results. In our overall analysis, the youngest age group had the longest STD. A slight, though nonsubstantive, prolongation was observed in the subsequent groups (2–4, see Table 3).

Taking bolus size into account, we extracted data on the larger boluses and reanalyzed for 5- and 10-mL boluses only. Results on STD, though still not significant, were in the direction we initially expected (see Fig 2). Larger boluses (20 mL) significantly affected STD than did 5- and 10-mL swallows. Removing this variability changed the progression of means across ages. Furthermore, our age groups were different in this investigation than in the prior report on STD.[17] The prior investigation divided participants into 2 groups: young (21–51 years) and old (70–87 years). In this study, not only were all ages 21 and older included but also were divided into 4 groups, none of which were exactly the same as those of the prior studies. Changing the age group divisions changes the individuals involved in the study. Twenty-one to 39 years age group incorporates a much smaller group of people than 21–51 years age group. Even within a specific age group variability can occur. Thus, changing age groups could have affected results. Again, when attempting to define "abnormal" swallowing in comparison with "normal," not only the obvious factors of bolus size and consistency should be considered but also the specific age divisions defined in various studies.

One final observation on STD relates to the difference with STD2. STD differs from STD2 in that it is initiated when the first sign of barium crosses the ramus of the mandible, rather than the head of the bolus, as is the case for STD2. Therefore, if the study clinician places a liquid bolus in someone's oral cavity, especially a large bolus, such as 20 mL, and asks the participant to pause and hold the bolus while the radiologist gets the videofluoroscopy turned on and adjusted as necessary, the participant may be holding the bolus against natural inclinations to swallow. And, in fact, we did observe a number of graduate students participating in this study who would refrain from swallowing even when the bolus leaked into the valleculae. These younger adults were not in danger of aspiration but were willing to withhold swallow onset until instructed to do so. This is in contrast to older adults who tended to swallow as soon as the bolus entered the oral cavity, some of whom may not have been able to hear the command to swallow or not to swallow. STD2, measuring from the *head of the bolus* passing the ramus to the onset of the pharyngeal swallow, reduces that variability by ensuring that everyone is measured for swallow onset *after* the oral, volitional movement has begun and the bulk of the bolus is moving, as anticipated, into the pharynx. In young, normal swallowers, STD2 is often a negative number because the onset of hyoid excursion actually begins *before* the head of the bolus reaches the ramus of the mandible. Recent research has reported that STD is useful for distinguishing aspirators from nonaspirators in patients subsequent to stroke (Kim et al, unpublished data). Despite this observation, the potential for methodological variation may lead researchers and clinicians to use the more stable measure of STD2. More research on STD2 and aspiration needs to be conducted to determine its value in separating aspirating patients from nonaspirators. Regardless, when extracting STD data for 5- and 10-mL thin liquid boluses and reanalyzing, results were much more consistent with previous findings; and both STD and STD2 increased with age.

While all other duration measures fell within the anticipated progression across gender, bolus size and bolus consistency slowed with age.

Gender

Prior research has reported that duration measures gradually increase with age in women similarly to men.[21,22,33] Although most measures were not significantly different with age, it was observed that as men aged, displacement of the hyoid and larynx decreased. In women, those displacements increased with age. This was postulated to mean that women have a greater "muscular reserve" than men and would, thus, be less prone to dysphagia with age than men. No differences were observed on penetration-aspiration scores between men and women, but men did have significantly more pyriform residue after the swallow and a fewer number of multiple swallows. When considering the findings of Logemann et al[21] and the relationship between hyolaryngeal displacement and upper esophageal sphincter opening, it is not surprising that pyriform residue increased in men, even if residue ratings may not be as specific as necessary to more clearly define the pattern. Why fewer swallows were elicited is more difficult to determine.

All duration measures that were significantly different between men and women in this investigation were prolonged in men except for DOOUES, which was significantly prolonged in women more than men in prior reports as well.[11,21] Further analyses regarding hyoid and laryngeal displacement are warranted with these data to consider the reasons for the other prolonged durations in men.

Bolus size and consistency

For all measures with a significant effect from bolus consistency or viscosity, duration measures increased with increasing viscosity (liquid, puree, solid). This is consistent with prior reports on most duration measures.[11] Prior research on patients with neurological impairment[9] has reported PDT, one of the other measures of swallowing delay, to decrease with increasing viscosity, something that was not observed with normal adults in the same study. Although the definitions of PDT, STD, and STD2 are different, additional comparisons of these measures in patients with neurological impairment across bolus consistency seems warranted. In the abovementioned study that reported differences in STD between aspirating and nonaspirating patients with stroke,[17] STD was prolonged in the aspirating patients and that study involved only thin liquid. Additional comparisons with larger and more viscous boluses would be valuable. If trends such as this hold up across studies, then very strong identifiers of dysphagia are developed. Care must be taken, however, when interpreting a prolonged STD as a "delayed swallow" for puree or solid consistencies. Food often collects in the valleculae long before a swallow is initiated.[34,35] STD2 takes this measurement into account by measuring from the bulk of the bolus passing the ramus of the mandible rather than the first sign of barium (see Fig 4b). STD2, therefore, may be of more value than STD for puree and solid consistencies. Regarding aspiration related to delayed swallow, again, most problems exist only for liquid consistencies.

DOOUES might be expected to increase with viscosity. This was not the case in this investigation, nor in the study of Robbins et al.[11] DOOUES was longer for liquid boluses than for puree or solid. Of course, larger boluses of thin liquid were employed. When comparing only 5-mL boluses across thin liquid, puree, and solid consistencies, almost no difference was observed for DOOUES. Lazarus et al[10] did report increased duration of upper esophageal sphincter opening with more viscous boluses. However, their study employed 1 mL and this one employed 5 mL for the analysis. Perhaps, with larger boluses, the same viscosity differences do not hold up. Again, more data would be necessary for an adequate comparison. An increased number of swallows were observed for increased viscosity. This has also been observed in at least one prior investigation.[36] While viscosity may not have significantly affected DOOUES, increasing bolus size did. This is consistent with reports of increased hyoid elevation with increasing bolus size,[37] as well as concurring reports regarding timing of the upper esophageal sphincter opening.[37,38,39]

SUMMARY

The findings of this investigation concur with prior reports that as people age, the physiology of the swallow tends to slow. Although this can provide valuable information for defining abnormal swallowing by comparison, great care should be taken in generalizing results. For example, positioning of the oral bolus prior to ingestion can dramatically change OTD. Different definitions for the transition between the end of the oral stage and the initiation of the pharyngeal swallow provide not only different durations but also sometimes different trends in both normal and neurologically impaired populations. Moreover, small adjustments in age groups from study to study may add to the already difficult task of comparing different types of bolus volumes and consistencies. Perhaps, most importantly, clinicians, whose task it is to evaluate and manage or treat older individuals with suspected dysphagia, must consider that when utilizing a scale sensitive to the severity of penetration-aspiration, such as an 8-point scale, as many of the "oldest old" experience laryngeal penetration as do not. Cutting swallow studies in the videofluoroscopy suite short or overmanaging with chin tucks, head turns, and thick liquids can reduce quality of life as quickly as frank aspiration can reduce safe nutritional intake.

Normative data should be carefully considered when evaluating and treating geriatric persons, but care must be taken to consider all potential factors, including bolus size, bolus consistency, gender, and age. More importantly, each patient comes with a unique collection of heredity, medical conditions, and tolerances. While none of the participants in this study had a history of head and neck cancer or neurologic insult, some participants did have existing medical conditions, such as diabetes and hypertension. Prior research has suggested even medical conditions such as hypertension may affect oropharyngeal swallowing function.[33] It is readily apparent that each patient who undergoes evaluation for swallowing function must be meticulously considered as an individual whose true outcome cannot be derived from data. After all, it is people who define the age groups. The age groups do not define the people.

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